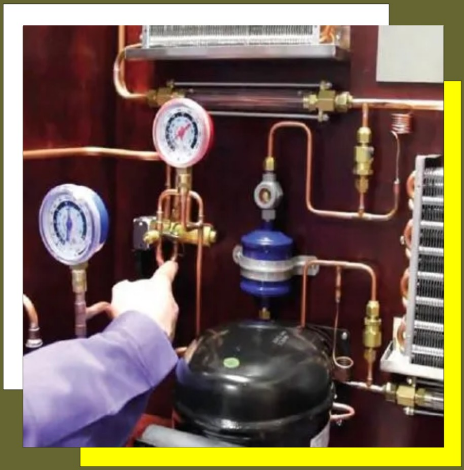
REFRIGERATION AND AIR CONDITIONING
MECHANICAL ENGINEERING

MECHANICAL ENGINEERING-ME



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REFRIGERATION AND AIR CONDITIONING

ENGINEERS
INSTITUTE OF INDIA

MECHANICAL ENGINEERING

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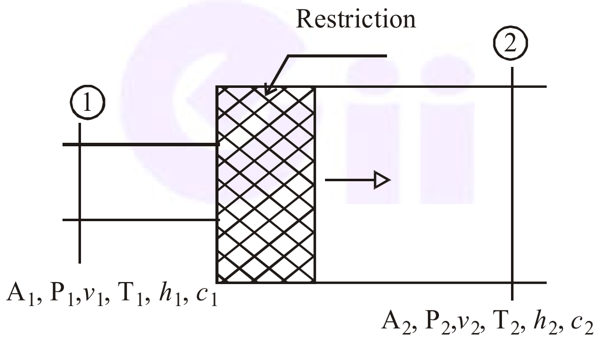
REFRIGERATION AND AIR CONDITIONING

CONTENT

CHAPTER-1

INTRODUCTION & BASIC CONCEPT

- Refrigeration is defined as the process of achieving and maintaining a temperature below that of the surrounding, the aim being to cool some product or space to the required temperature.
- Saturation pressure is defined as that pressure at which liquid is in equilibrium with its vapour. It depends up on temperature only.
- Intensive properties are defined as the properties which do not depend on mass or size of the system. e.g. temperature, pressure, density.
- Extensive properties are defined as the properties which depend on mass or size of the system. e.g. weight, enthalpy.
- Throttling process is an irreversible adiabatic flow process. It is used to reduce the pressure of a fluid by introducing a restriction to the flow. This process is also known as Isenthalpic process (constant enthalpy process).



As the process is adiabatic and no external work is done than SFEE.

$$gz_1 + h_1 + \frac{c_1^2}{2} + Q = h_2 + \frac{c_2^2}{2} + gz_2 + w$$

$$h_1 + \frac{c_1^2}{2} = h_2 + \frac{c_2^2}{2}$$

Since $P_1 < P_1, V_2 > V_1$. Hence if $A_1 = A_2, c_2 > c_1$. making $A_2 > A_1$ such that $c_2 = c_1$ so kinetic energy change is negligible.

So. $\boxed{h_1 = h_2}$ Isenthalpic expansion.

Types of Refrigeration System:

1) Natural refrigeration system.
    - i. By nocturnal cooling
    - ii. Evaporative cooling
    - iii. Cooling by salt solution.
2) Artificial refrigeration system.
    - i. Vapour compression refrigeration system.
    - ii. Vapour absorption refrigeration system.
    - iii. Gas cycle refrigeration system.
    - iv. Steam jet refrigeration system.
    - v. Thermoelectric refrigeration system.
    - vi. Vortex tube refrigeration system.

Natural refrigeration system:

- It is mainly achieved by the use of ice or evaporative cooling.

Nocturnal cooling:

- In this method, water looses heat by radiation to the stratosphere, which is at around -55^{o}C and by early morning, water in tray freezes to ice.

Evaporative cooling:

- It is the process of reducing the temperature of a system by evaporation of the water. human being perspire and dissipate their metabolic heat by evaporative cooling if ambient temperature is greater than the body temperature.
- Now-a-days, desert coolers are being used in hot and dry areas to provide cooling in summer.

Cooling by salt solution:

- Certain substance such as common salt, when added to water dissolve in water and absorb its heat of solution from water(endothermic process). this reduces the temperature of solution(water + salt).

Gas cycle refrigeration system:

- If air at high pressure expands and does work (say moves a piston), its temperature will decrease. On this principle, this system works.
- These days air cycle refrigeration system is used only in aircraft.

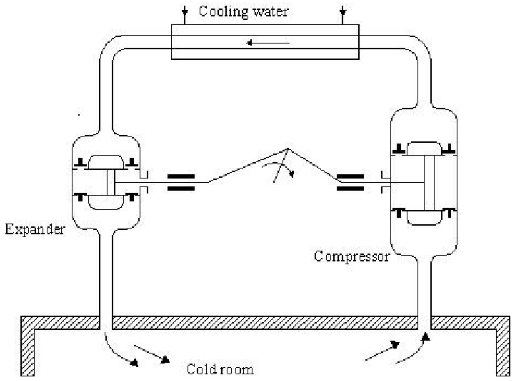


Figure: Schematic of a basic, open type air cycle refrigeration system.

Steam jet refrigeration system:

- If water is sprayed into a chamber where low pressure is maintained, a part of the water will evaporate. The enthalpy of evaporation will cool the remaining water to its saturation temperature at the pressure in the chamber. On this principle, this system works.
- Water freezes at 0^oC hence temperature lower than 4^oC cannot be obtained with water.
- In this system, high velocity steam is used to entrain the evaporating water vapour. High pressure motive steam passes through either convergent or convergent-divergent nozzle where it acquires either sonic or supersonic velocity and low pressure of the order of 0.009 kPa corresponding to an evaporator temperature of 4°C. the high momentum of motive steam entrains or carries along with it the water vapour evaporating from the flash chamber. Because of its high velocity it moves the vapours against the pressure gradient up to the condenser where the pressure is 5.6-7.4 kPa corresponding to condenser temperature of 34-35°C. The motive vapour and the evaporated vapour both are condensed and recycled.
- This system is driven by low grade energy that is process steam in chemical plants or boiler.

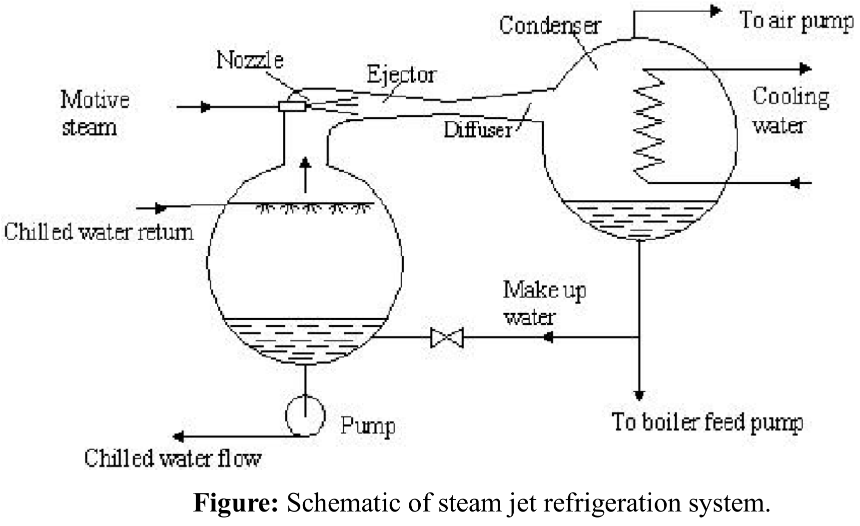


Figure: Schematic of steam jet refrigeration system.

Thermoelectric refrigeration system:

- Cooling is produced of one junction of two dissimilar metals, if a current is passed through them. Heat transfer rate being proportional to the current. This phenomenon is called the Peltier effect.

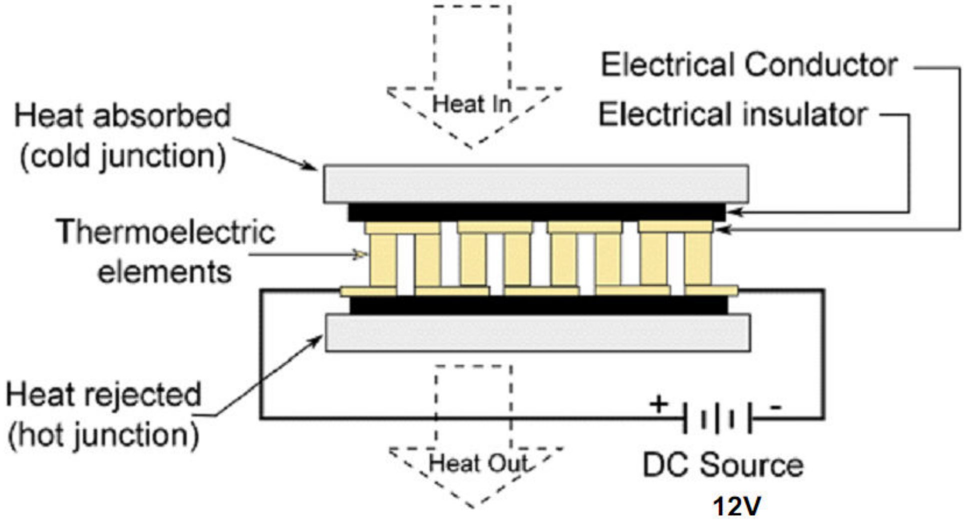


***Fig. 1.8**. Schematic of a thermoelectric refrigeration system*

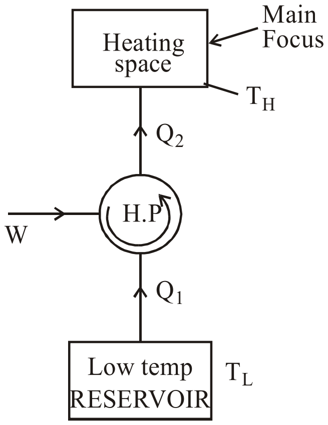
Vortex tube refrigeration system:

- Tangential injection of air in to a vortex tube induces giratory expansion with simultaneous production of an escape of hot air and an escape of cold air.
- Currently, it is used for spot cooling of machine parts, in electronics cooling and also in cooling jacket for miners, firemen.

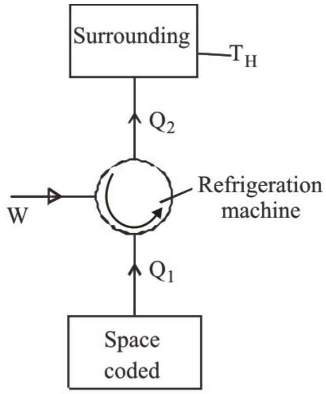
Heat Engine, Heat Pump:

- HEAT Engine may be defined as a device which is working on a cyclic process and convert heat energy in to mechanical work. E.g. steam power plant
- Heat pump may be defined as a device which is working on a cyclic process and maintains the temperature of a given space above the ambient temperature. It draws heat from a low temperature body and transfers it to the high temperature body.
- Refrigerating machine may be defined as a device which is working on a cyclic process and maintains the temperature of a given space below the ambient temperature.
- There is no difference between heat pump and refrigerating machine in their cycle of operation, but purpose is different. purpose of refrigerating machine is to cool the given space(that is, it operates between the ambient temperature T_a and a low temperature T_o),while the purpose of refrigerating machine is to heat the given space(that is, it operates between the ambient temperature T_a and a high temperature T_h).
- A refrigerating machine that is used for cooling in summer can be used as a heat pump in winter in the following ways:

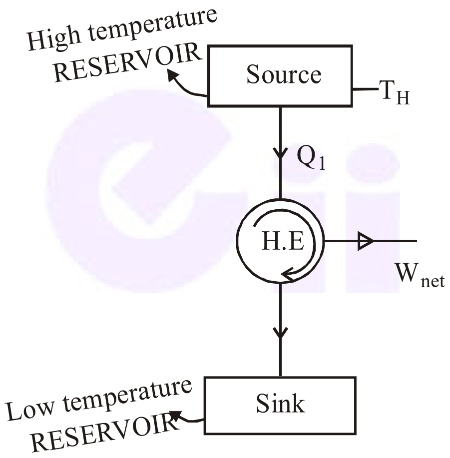
- By rotating the machine by 180° to interchange the position of the two heat exchangers between the space and surrounding.
- By exchanging the function of the two heat exchangers by the operation of valves.



Heat Pump



Refrigrator



Heat engine

CO-EFFICIENT OF PERFORMANCE:

$$\text{co-efficient of performance} = \frac{\text{effect desired}}{\text{input energy}}$$

For Heat Pump:

$Q_2 = Q_1 + W_{net}$

$$COP = \frac{net\ effect\ desired}{input\ energy}$$

$$= \frac{Q_2}{W_{net}}$$

$$= \frac{(Q_2)}{(Q_2)-(Q_1)} \qquad ..(1)$$

For Refrigerating Machine:

$Q_2 = Q_1 + W_{net}$

$$COP = \frac{net\ effect\ desired}{input\ energy}$$

$$= \frac{Q_1}{W_{net}}$$

$$= \frac{(Q_2)}{(Q_2)-(Q_1)} \qquad ...(2)$$

From equation (1) and (2), it is clear that,

$(COP)_{HP} = 1 + (COP)_R$

As we know from the Carnot's theorem that for a reversible cycle, $\left(\frac{Q_1}{Q_2}\right)$ is a function of temperature of the two reservoir only. It does not depend on the property of the working fluid.

If we choose the Kelvin temperature scale then:

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

This Kelvin temperature scale can use only if cycle is reversible.

Hence,

$$(COP)_{HP,\ carnot} = \frac{T_2}{(T_2)-(T_1)} \qquad \& \qquad (COP)_{R,\ carnot} = \frac{T_1}{(T_2)-(T_1)}$$

Carnot's theorems for heat engines:

Theorem 1: No engine working on a cyclic process is more efficient than a carnot engine working between the same temperature limit.

Theorem 2: All reversible heat engines occur between the same temperature limit, will have the same efficiency.

These two theorems are same and can be proved.

Carnot efficiency of heat engine:

Carnot efficiency of a heat engine represents the efficiencies of an reversible heat engine operating between the given temperature limits. It represents the maximum possible efficiency.

$$Thermal\ efficiency\ of\ an\ heat\ engine = \frac{net\ work\ output}{heat\ input} = \frac{W_{net}}{Q_{input}}$$

$$= \frac{(Q_1)-(Q_2)}{(Q_1)}$$

- Water as a cooling medium is preferable to air due to following reason:
    - Available at a lower temperature than that of the air, its temperature approaches we bulb temperature of the surrounding air.
    - Specific heat of water is about 4 times that of the air.
    - Water has a higher heat transfer co-efficient than air mainly because of its high thermal conductivity.
- Temperature approaching zero have been obtained by adiabatic demagnetization of a paramagnetic salt on a limited scale in laboratories.

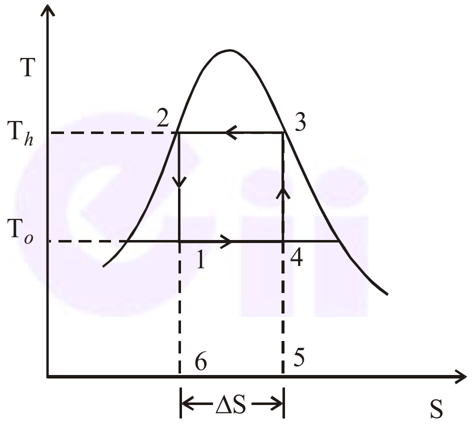
Limitations of Carnot cycle:

- It's difficult to achieve isothermal heat transfer in the Carnot cycle.
- Volumetric refrigeration capacity of the Carnot system is very small leading to large compressor development, which gives rise to large frictional loss.
- All actual processes are irreversible; hence completely reversible cycles are idealization only.

Reversed Carnot Cycle:

- Reversed Carnot cycle is an ideal refrigeration cycle for constant temperature external heat source and heat sink. In this cycle, two isothermal process of Carnot cycle is replaced by two isobaric process.
- This cycle is used for aircraft refrigeration.

Process 1-2	isentropic compression
Process 2-3	isothermal heat rejection to the hot reservoir at T_h = const.
Process 3-4	isentropic expansion
Process 4-1	isothermal heat absorption from a cold reservoir at T_c = const.



Heat absorbed from cold body, $Q_C = T_0 \Delta S$ = area 1-4-5-6

Heat rejected to the hot body, $Q_H = T_h \Delta S$ = area 2-3-5-6

Work done = $Q_H - Q_C = (T_h - T_0)\,\Delta S$ = area 1-2-3-4

$$(\text{COP})_{\text{Carnot, heating}} = \frac{Q_h}{(Q_h)-(Q_c)} = \frac{T_h}{(T_h)-(T_c)}$$

$$(\text{COP})_{\text{Carnot, cooling}} = \frac{Q_c}{(Q_h)-(Q_c)} = \frac{T_c}{(T_h)-(T_c)}$$

Effect of Operating Temperature:

- Lowest possible refrigeration temperature is absolute zero temperature while highest possible refrigeration temperature is ambient temperature. Thus, Carnot COP for cooling varies between 0 and ∞.
- For heating, T_h may tend to ∞. Theoretically, the COP for heating varies between 1 and ∞.
- To obtain maximum possible COP in any application,

  - The cold body temperature T_c should be as high as possible.
  - The hot body temperature T_h should be as low as possible.
- The selection of temperature T_h depends on the surrounding medium used for heat rejection such as air, water.
- The lower the refrigeration temperature required, and higher the temperature of heat rejection to the surrounding, the larger is the power consumption of the refrigerating machine. Also, the lower is the refrigeration temperature required, the lower is the refrigerating capacity obtained.

Drawback of using Air as Refrigerant in Reversed Carnot Cycle:

- Due to isentropic compression, very high pressure and due to isothermal heat rejection, very high volume of gas is developed.
- Isothermal heat transfer with a gas is not possible due to very small specific heat of the gas.
- Small irreversibility in a gas cycle causes much increase in work due to narrowness of the cycle.

Vapour As A Refrigerant In Reversed Carnot Cycle:

- Isentropic expansion of the liquid from 3 to 4 results in flashing of the refrigerant with consequent temperature drop from T_h to T_c , although such expansion of a liquid with partial vaporization is practically difficult to achieve in a fast moving piston and cylinder mechanism.

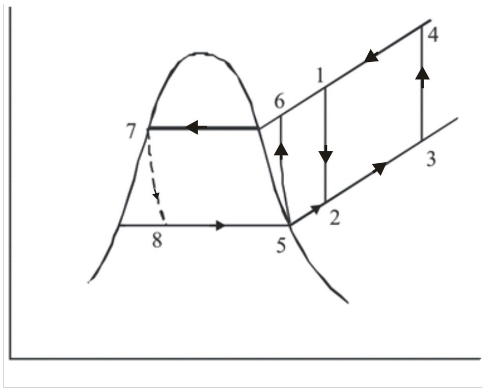
Drawback of using Vapour as Refrigerant in Reversed Carnot Cycle:

- Liquid refrigerant may trapped in the head of the cylinder and damage the compressor valves.
- Liquid refrigerant may wash away the lubricating oil from the walls of compressor cylinder.
- It is difficult to design an expander to handle a mixture of largely liquid and partly vapour. Also, because of the internal irreversibility in the compressor and expander, the actual COP of the Carnot cycle is very low.

Comparison between gas cycle and vapour cycle:

- In gas cycle, the working fluid does not undergo phase change, whereas in vapour cycle, the working fluid undergoes phase change.

e.g.



5-6-7-8 → Vapour compression cycle.

↓

(*Phase change of working fluid*)

3-4-1-2 → Reversed bryton cycle

↓

(*No phase change of working fluid*)

- In gas cycle, heat rejection and refrigeration take place as the gas undergoes sensible cooling and heating. In a vapour cycle, refrigeration effect is due to the vaporization of refrigerant liquid.
- In a vapour cycle, the required mass flow rates for a given refrigeration capacity will be much smaller as compared to a gas cycle.

Actual refrigeration system:

- For the purpose of comparison between the actual and Carnot values, we define second law efficiency for cooling and heating.

$$(\eta_{II})_C = \frac{\eta_C}{\eta_{C,Carnot}}$$

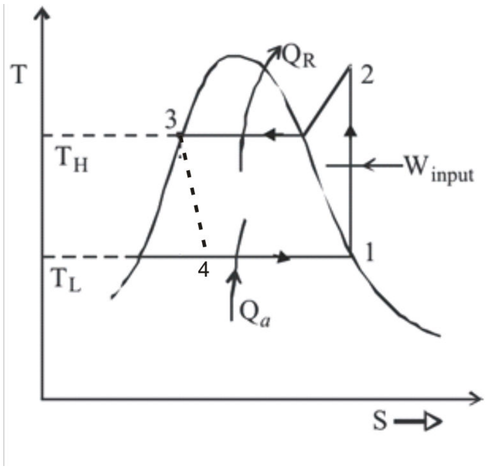
$$(\eta_{II})_h = \frac{\eta_h}{\eta_{h,Carnot}}$$

Unit of Refrigeration:

- It is generally defined in terms of **ton of refrigeration**.
- A ton of refrigeration is defined as the quantity of heat to be removed in order to form one ton of ice at 0°C in 24 hours, from liquid water at 0°C. It is denoted by the symbol TR.

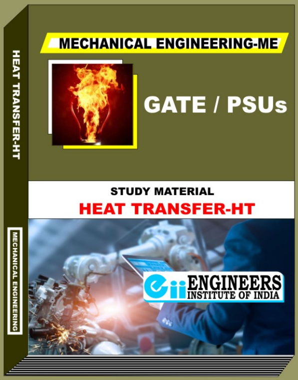
  1 TR= 3.5kJ/sec.= 50 kcal/min.

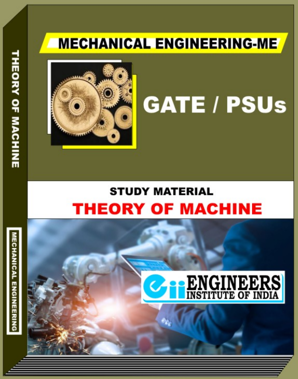
Important Points

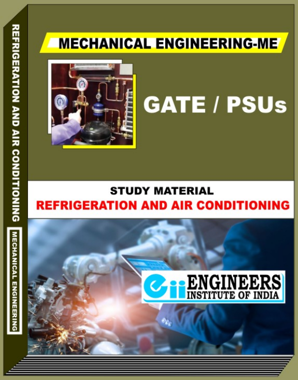


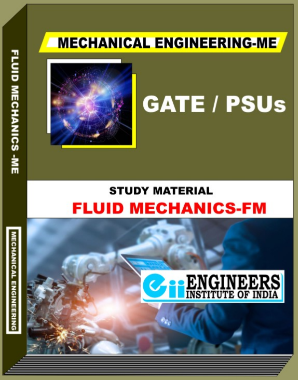
- $(COP)_R = \frac{Q_a}{W_{input}}$

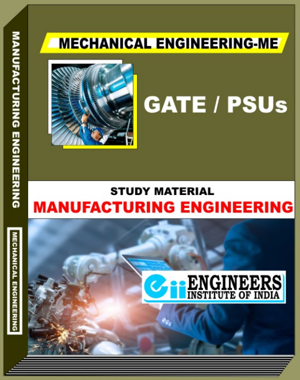
Published Books

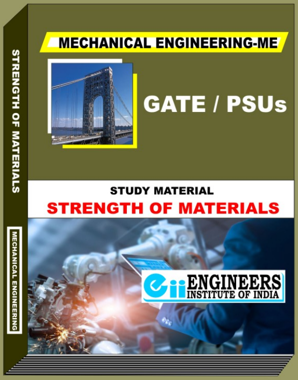


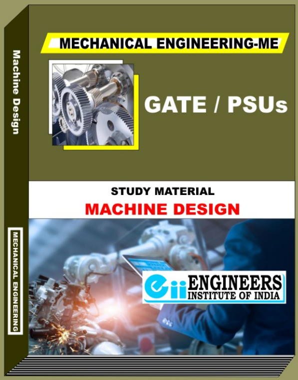


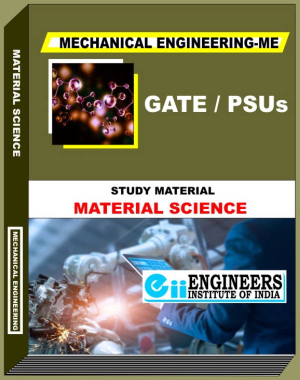












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